Latency and Its Effects on the Fidelity of Air-to-Air Missile T&E Using Advanced Distributed Simulations

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ABSTRACT: *The Linked Simulators Phase (LSP) of the Systems Integration Test (SIT) was executed by the Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF) and the Naval Air Warfare Center, Weapons Division (NAWCWPNS) between August and November 1996. The purpose of the SIT is to evaluate the utility of using advanced distributed simulations (ADS) to support cost-effective testing of an integrated missile weapon/launch aircraft system in an operationally realistic scenario. The SIT missions simulate a single shooter aircraft launching an air-to-air missile against a single target aircraft.*

In the LSP, the shooter, target, and missile were all represented by simulation laboratories. ADS techniques were used to link NAWCWPNS manned flight laboratories representing the aircraft to an air-to-air missile hardware-in-the-loop (HWIL) laboratory representing the missile. In order for this linking to have utility for the T&E of the AIM-9M missile under test, the latency of the data exchanged between the laboratories must be sufficiently low and well-behaved so as not to adversely affect the fidelity of the missile laboratory performance. This paper presents the results of the evaluation of latency and its effects on LSP results. Conclusions for T&E applications of the LSP ADS configuration are also given.

1. Overview

The Linked Simulators Phase (LSP) of the Systems Integration Test (SIT) was executed by the Joint Advanced Distributed Simulation (JADS) Joint Test Force (JTF) and the Naval Air Warfare Center, Weapons Division (NAWCWPNS) between August and November 1996. The purpose of the SIT is to evaluate the utility of using advanced distributed simulations (ADS) to support cost-effective testing of an integrated missile weapon/launch aircraft system in an operationally realistic scenario. The SIT missions simulate a single shooter aircraft launching an air-to-air missile against a single target aircraft. The scenario utilized in the LSP missions was taken from previous Sidewinder AIM-9M testing and is shown in Figure 1.

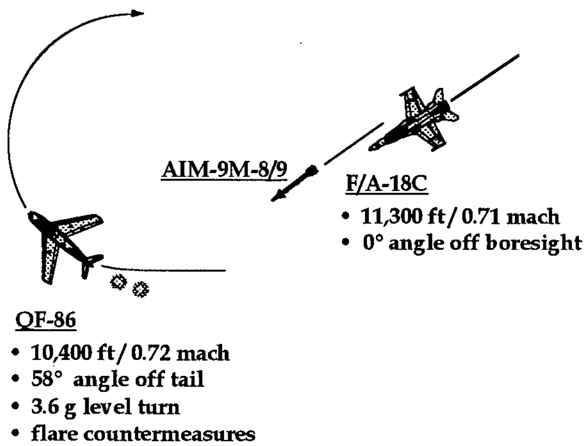

Figure 1. AIM-9M-8/9 Live Fire Profile (LPN-15, 9 June 93)

In the LSP, the shooter, target, and missile were all represented by simulators. ADS techniques were used to link NAWCWPNS manned flight laboratories representing the aircraft to an air-to-air missile hardware-in-the-loop (HWIL) laboratory representing the missile. The LSP test configuration is shown in Figure 2. The F/A-18 Weapon System Support Facility (WSSF) at China Lake and the F-14D Weapon System Integration Center (WSIC) at Point Mugu were the shooter and target, respectively. These laboratories were linked to each other and to an AIM-9M-8/9 HWIL laboratory at the Simulation Laboratory (SIMLAB) at China Lake. The launch aircraft laboratory "fired" the AIM-9 in the SIMLAB at the simulated target aircraft, and the AIM-9 seeker responded to infrared (IR) sources in the SIMLAB which simulated the IR signatures and relative motions of the target aircraft and the flare countermeasures. Real-time links between the laboratories allowed the players to respond to each other.

The nodes exchanged entity state information with each other by means of Distributed Interactive Simulation protocol data units (DIS PDUs). However, the Stores Management System (SMS) data exchanged between the F/A-18 WSSF and the AIM-9 SIMLAB used the tactical MIL-STD-1553 protocol, because no suitable DIS protocol exists for these data, because this exchange was only between the WSSF and the SIMLAB, and because use of the tactical protocol was appropriate for integrated weapon system testing.

In order for this linking to have utility for the T&E of the AIM-9M missile under test, the latency of the data exchanged between the simulation laboratories must be sufficiently low and well-behaved so as not to adversely affect the fidelity of the AIM-9M HWIL laboratory output.

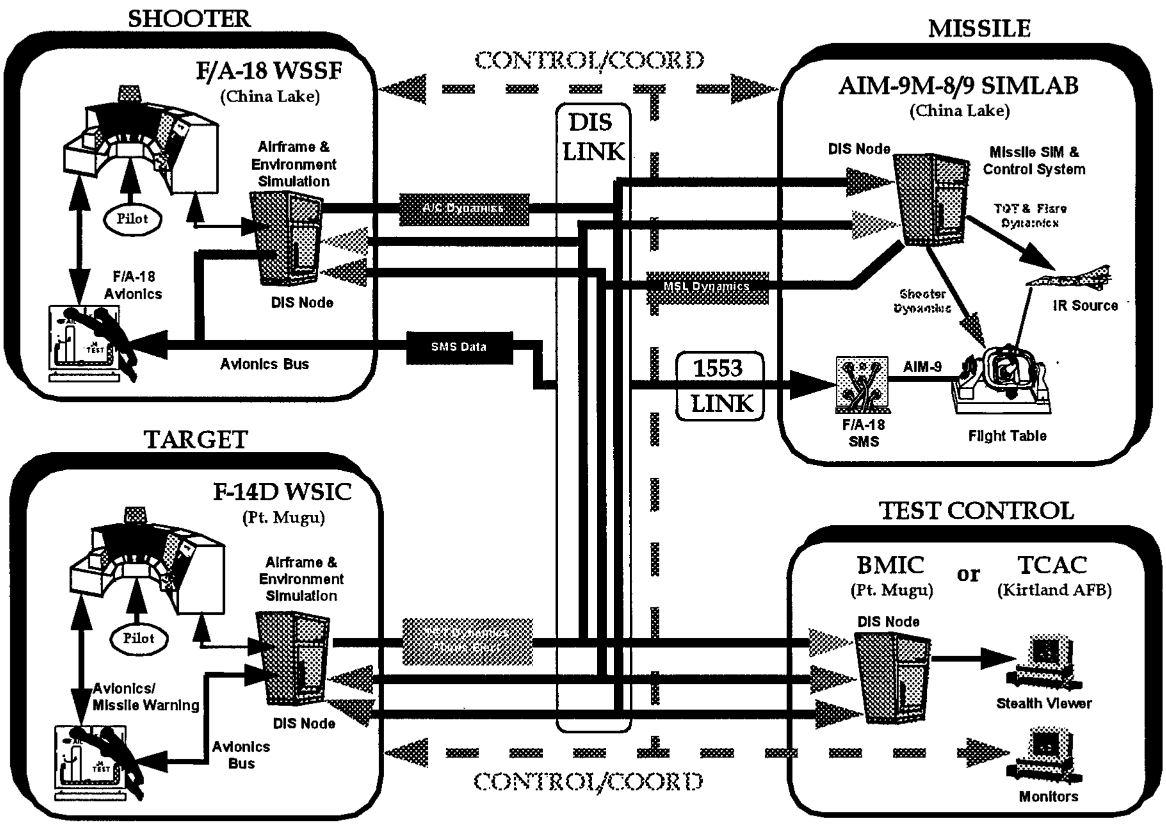

Figure 2. Linked Simulators Phase Test Configuration

2. Latency Results

During periods of linked testing, the aircraft simulation laboratories executed the scenario depicted in Figure 1, and the data transmitted between the various nodes shown in Figure 2 were analyzed to determine the characteristics of the latency for the various data transfers and the effects of that latency.

2.1 Latency Characteristics

Latency values were calculated throughout a run from the differences in time stamps for the same set of entity state data logged at various locations. The latency was characterized by its time variation, frequency distribution, mean value, standard deviation, minimum value, and maximum value.

Examination of the results showed that the entity state data between any two laboratories was not constant during a trial, but exhibited significant sample-to-sample variations. During the initial linking attempts, latencies of some of the data occasionally exceeded one second. By adjusting the network interface units (NIUs) at each node and by resetting the NIUs after each run, the mean latencies between laboratory simulations was reduced to 70 ms, or less. Target entity state data latency characteristics for the final mission were as follows (target data is highlighted because the target (WSIC) data were inputs to the shooter (WSSF) and missile (SIMLAB) simulations):

- The mean latency of the target entity state data between the WSIC and the WSSF simulations was 66.2 ms with a standard deviation of 23.9 ms. These variations represented about 35% of the mean value.
- The mean latency of the target entity state data between the WSIC and the SIMLAB simulations was 70.0 ms with a standard deviation of 41.2 ms. These variations represented about 60% of the mean value.
- The largest contribution to these total latencies was between the PDU logger at the receiving node and the receiving simulation. The mean latency for target data between the WSSF PDU logger and the WSSF simulation was 38.1 ms (58% of the total), and the mean latency between the SIMLAB PDU logger and the

SIMLAB simulation was 45.1 ms (64% of the total).

- The smallest contribution to these total latencies was between the originating simulation and the PDU logger at the originating node. The mean latency for target data between the WSIC simulation and the WSIC PDU logger was about 10 ms (~15% of the total).
- The latency for transmission of the PDUs between nodes was typically about 20 ms (~30% of the total).

An example of some of the larger variations in the latency of the target entity state data is shown in Figure 3. Note that on a given run, the latency could vary significantly.

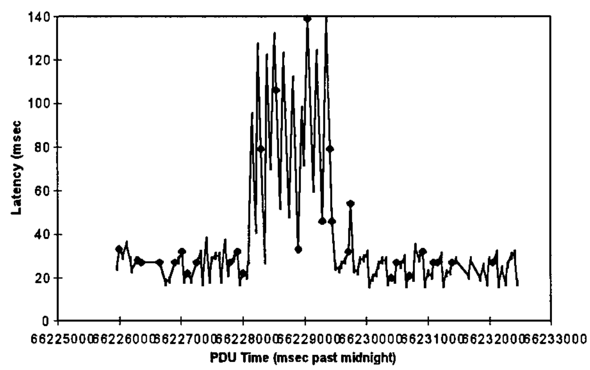

Figure 3a. Latency of Target Entity State Data Between WSIC Simulation and SIMLAB PDU Logger (Run #19 on 11/19/96)

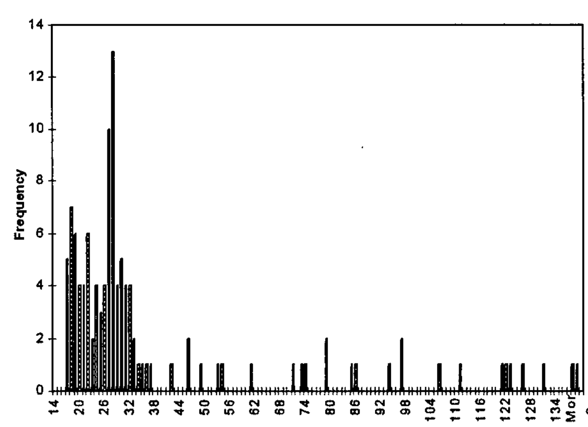

Figure 3b. Frequency Histogram of Latency of Target Entity State Data Between WSIC Simulation and SIMLAB PDU Logger (Run #19 on 11/19/96)

2.2 Latency Effects - Entity Presentation Errors

The random variations in latency between the WSIC and the SIMLAB during a run resulted in an uncertainty in the target location, as perceived at the SIMLAB. Comparing the data received at the SIMLAB (curve (2) of Fig. 4) with the WSIC output (curve (1) of Fig. 4) showed that the SIMLAB received a target time history in which the individual data points were "misaligned" in time. In other words, the time history went from a smooth shape at the WSIC to an "unsmoothed" shape at the SIMLAB. This was caused by variations in the WSIC-to-SIMLAB latency and distorted the target time histories. If the latency had been constant, the SIMLAB trajectory would have had the same shape as the WSIC trajectory, but delayed in time by a fixed amount (the latency value). Also, note that the target data were input into the SIMLAB simulation at a higher rate than the received data (curve (3) of Fig. 4) and that the SIMLAB input was determined by dead reckoning the received data, resulting in additional distortion.

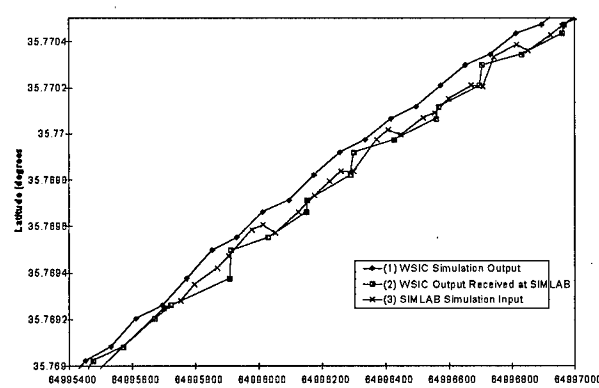

Figure 4. Target Latitude versus Time During Run #23 (10/29/96)

The "distortion" illustrated in Figure 4 resulted in an uncertainty in the target location at the SIMLAB, analogous to range TSPI measurement error in live testing. A measure of this uncertainty was given by multiplying the standard deviation of the WSIC-to-SIMLAB latency by the target velocity. The result was an average uncertainty of about 32 ft in the target position input into the SIMLAB laboratory. This is significantly larger than the lethal radius of the missile, so that lethality results from the LSP configuration cannot be considered valid. Also, note that the uncertainty value quoted is based on the standard deviation of the latency. Some of the high

latency "spikes" were up to ten times the standard deviation, so that the observed target position might instantaneously diverge from its correct location by over 300 ft.

This uncertainty in target position did not directly affect the SIMLAB HWIL simulation performance. This is because the SIMLAB HWIL simulation did not directly use the target position to control the IR source representation to the AIM-9M seeker. Instead, the target velocity was used to control the IR source motion, and the velocity was integrated to determine the target position. The effect of the random latency variations was to cause deviations in the integration time intervals, so that the target location determined by the simulation diverged from the true value (the SIMLAB simulation assumed the target velocity remained constant at the current value from the entity state PDUs; velocity was not dead reckoned, even though the target was constantly accelerating during its 3.6g turn). The combined effect of deviations in the target velocity update time (due to random latency variations) and the assumption of constant target velocity between updates resulted in a difference between the target location computed by the SIMLAB and the true target location of about 36 ft by the end of the missile flyout.

Note that the random nature of the latency variations prevent the application of any deterministic real-time corrections for this effect.

2.3 Latency Effects - Launch Condition Differences

The launch conditions were determined from the shooter and target entity state data collected at each node (WSSF, SIMLAB, WSIC, and TCAC). The shooter and target data logged at each node at the time the missile launch indication was received were combined to compute the launch range, target aspect angle, and lead angle as perceived at that node (Figs. 5 and 6 illustrate the definitions of target aspect angle and lead angle). The launch conditions determined for the various nodes were compared, and the differences in launch parameters were computed.

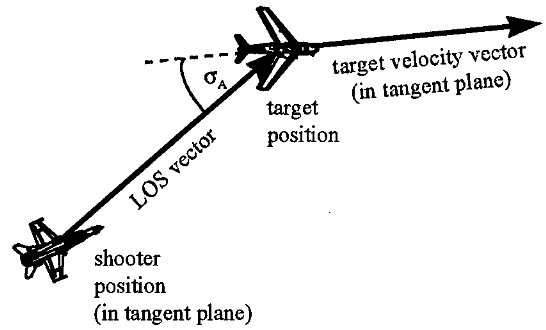

Figure 5. Geometry for Calculating Target Aspect Angle, σ_A (engagement projected into horizontal tangent plane)

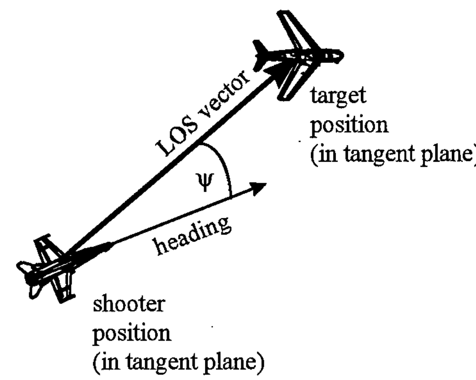

Figure 6. Geometry for Calculating Lead Angle ψ (engagement projected into horizontal tangent plane)

Data from the early linking attempts with large latencies were examined, and latencies in excess of several hundred milliseconds were found to result in significant differences in the launch conditions perceived at the different nodes. An example is given in Figure 7. This figure shows the differences in the launch ranges perceived by the missile (SIMLAB) and shooter (WSSF) simulations as a function of the latency of the shooter entity state data received at the SIMLAB relative to the latency of the launch indication received at the SIMLAB from the WSSF (i.e., launch range difference versus the latency difference).

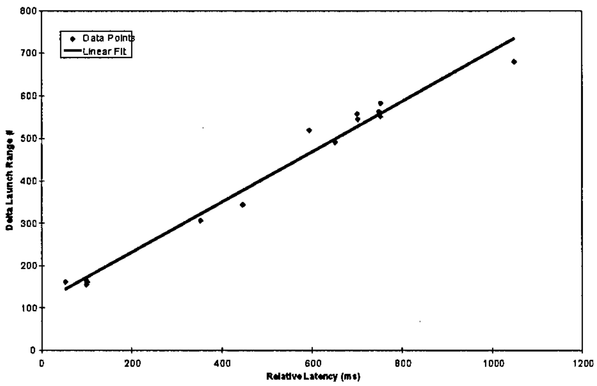

Figure 7. Launch Range from SIMLAB Simulation Data Relative to Launch Range from WSSF Simulation Data vs. Shooter Entity State Data Latency at SIMLAB Relative to SIMLAB Launch Indication Latency (10/29/96)

The latency differences in Figure 7 were mainly due to the latency of the shooter entity state data (the latency of the launch indication at the SIMLAB was relatively small and constant). Figure 7 implies that the latency of the entity state data must be less than about 100 ms for good agreement in launch conditions. Note that the linear fit in Figure 7 does not pass through the origin due to the latencies of other data used to determine launch range (primarily the target entity state data).

During later linked testing, the latencies for all entity state data was significantly reduced, as discussed above. Data from these runs showed much smaller differences between launch conditions at the different nodes. In particular, the differences between the launch conditions determined by the target (WSIC) simulation and the shooter (WSSF) simulation were as follows:

- The mean difference in launch range was about 82 ft.
- The mean difference in target aspect angle was 1.3°.
- The mean difference in lead angle was 0.7°.
- The corresponding latencies for these differences were up to 200 ms.

These differences are compared to the shot box tolerances allowed during the testing. The tolerances were used to judge if a particular trial was "close enough" to the LPN-15 launch conditions (Fig. 1) such that the results of the trial could be compared directly to the live test results. These tolerances were ±1500 ft in launch range, ±10° in target aspect angle, and ±5° in lead angle. Hence, the differences in launch conditions between the shooter and target node observed in the low-latency trials were about 10% of the shot box tolerances and were judged to be quite acceptable.

The conclusion is that the small and relatively stable latencies achieved during the later testing resulted in good agreement in the launch conditions observed by the various entity nodes. In particular, the shooter and target simulations were in sufficient agreement to allow this ADS architecture to be used for pre-launch, closed-loop interactions, such as rehearsal and refinement of live engagement scenarios.

2.4 Latency Effects - Terminal Engagement Differences

The terminal range was the range between the missile and the target when the SIMLAB simulation stopped the missile flyout. Typically, the missile had a time to go of 100 msec at this time. The terminal range was not the miss distance. Rather, the miss distance was estimated in the SIMLAB simulation by dead reckoning the missile and target velocities from the terminal range until the distance of closest approach was obtained.

The terminal range determined at the missile node was compared to that determined at the target node. On half of the runs examined, the differences in the terminal ranges exceeded 30 ft. These differences exceeded the lethal radius of the missile, so that in these cases it was possible for the missile and the target nodes to disagree on whether or not the target had been "killed." Hence, terminal engagement results for a closed-loop interaction between the missile and target (in which the missile and target react to each other) would be invalidated.

3. Summary and Conclusion

Improvements in the NIU settings and operations allowed the latencies to be greatly reduced over the course of the LSP testing. However, the latencies exhibited significant sample-to-sample variations during a run (the standard deviation of the latency was a significant fraction of the mean value). Much, but not all, of this variation appeared to be caused by the interface between the simulation and the NIU at the receiving node.

The latency variations can distort entity state data received by a simulation, since the data were input into the simulation at the rate the data were received. The random nature of the latency variations prevent the application of deterministic corrections for this latency effect.

Latencies in the later LSP testing were small enough (less than 200 msec between simulations) to allow the simulation laboratories to agree on the launch conditions to within less than 10% of the shot box tolerances. This indicates that the LSP architecture has utility for the rehearsal and refinement of launch conditions for live mission scenarios.

However, the latencies were too large to allow reliable evaluation of a closed-loop terminal engagement between the missile and target, since the target and missile nodes could disagree on whether or not the target had been "killed." Future applications of this type will require significant reductions in the latencies and latency variations observed in the LSP trials.

On the other hand, the LSP architecture does appear to have utility for evaluation of an open-loop terminal engagement between the missile and target (in which the missile reacts to the target, but the target does not react to the missile). This type of scenario can be run with a significant target-to-missile latency, as long as the latency is relatively constant.

Author Biography

DR. LARRY MCKEE has 25 years experience directing and performing R&D programs in DT&E, nuclear weapon effects, system survivability, neutral particle beam interactive discrimination, and high energy laser effects. This experience includes 20 years as an Air Force officer with duties in management of advanced R&D programs in directed energy weapon technology, R&D leadership at the Air Force Branch and Division levels, development and instruction of advanced graduate courses, and technical direction of underground nuclear tests. He joined SAIC in 1989 and currently supports the JADS JT&E as the technical lead for the System Integration Test, designed to evaluate the utility of ADS for the T&E of integrated launch aircraft/missile systems.

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